Nonlocality of the Nucleon Axial Charge and Solar Neutrino Problem

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Abstract

It is shown that the specific space distribution of the nucleon axial charge may lead to the significant reduction of the cross section of the reaction $p + p \to D + e^+ + \nu$ and may provide the mechanism to explain observed deficit of solar neutrinos.

The deficit of solar neutrinos is one of the longstanding unsolved problem in astrophysics (see review [1]). The reaction $p + p \to D + e^+ + \nu$ is most important process which cross section determines the solar neutrino flux from pp cycle. Its value has never been directly measured and only theoretical predictions exist so far. There is a wide spread opinion that theoretical uncertainties in the calculation are very small and therefore one can conclude that it is impossible to explain the small observed flux of solar neutrinos without involving new physics (e.g. neutrino oscillations etc).

In this Letter we will show that rather extended space distribution of nucleon axial charge may lead to significant reduction of the cross section of the reaction $p + p \to D + e^+ + \nu$.

The main assumption which was used to calculate the rate of this reaction was the hypothesis of the locality of nucleon axial charge [2]. As the result, the cross section is proportional to product of two factors

$$\sigma_{FA}^{p+p\to D+e^+ +\nu} \propto g_A^2 |\int \Psi_D^* \Psi_{pp} d\vec{r}|^2, \tag{1}$$

where factor g_A, axial charge of nucleon, comes from weak interaction matrix element, and second factor is overlapping of Ψ_D, deutron wave function and

Ψ_{pp}, the initial wave function of two protons. We should emphasize that such approach can be correct only for the point-like distribution of the nucleon axial charge, i.e. only for the case when the characteristic scale of axial charge distribution is much smaller than the corresponding scale related to overlapping of initial and final hadron wave functions.

Recently Jaffe has shown [3] that the distribution of axial charge of the nucleon is rather nonlocal and in chiral limit $m_\pi \to 0$ one third of g_A comes from infinite distance $R \to \infty$ from the center of nucleon. It means that in this limit one should expect that cross section of the reaction $p + p \to D + e^+ + \nu$ should be much smaller than its factorized value (1)

$$\sigma^{p+p\to D+e^+ +\nu}(m_\pi \to 0) = \frac{4}{9}\sigma_{FA}^{p+p\to D+e^+ +\nu}. \tag{2}$$

The chiral limit is a rather good approximation for many calculations in hadronic physics and therefore it would be difficult to believe that factorization hypothesis would give the correct answer in the case of the physical pion mass. For finite mass of pion the contribution to axial charge from the

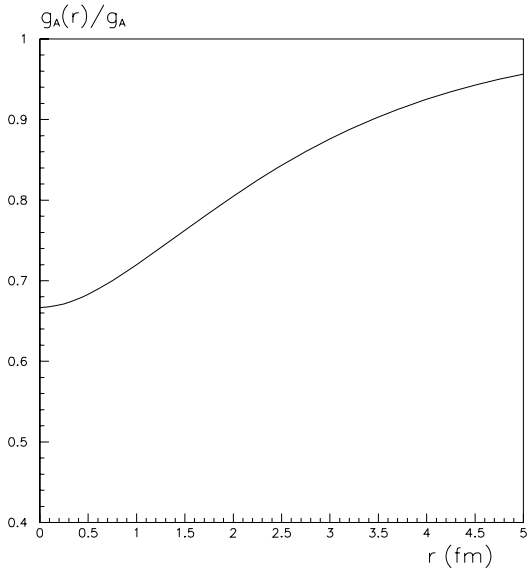

Figure 1: *The contribution to nucleon axial charge from distances $r < R$.*

distances $r < R$ is [3]

$$g_A(R) = g_A(1 - \frac{1}{3}(1 + m_\pi R)e^{-m_\pi R}), \tag{3}$$

where $g_A = 1.26$ is total nucleon axial charge. In Fig.1 the distribution of $g_A(R)$ is shown. It is evident that the distribution is quite extended and therefore the locality approximation which was used to get Eq.(1) is not very well justified.

Nonlocality of axial charge leads to suppression of the reaction $p + p \to D + e^+ + \nu$ due to smaller value of effective $\tilde{g}_A$ which should enter in Eq. (1).

One can roughly estimates the effect of suppression by using the formula

$$\frac{\sigma^{p+p\to D+e^+ +\nu}(m_\pi)}{\sigma_{FA}^{p+p\to D+e^+ +\nu}} \approx \frac{g_A^2(R_{eff})}{g_A^2}. \tag{4}$$

In Eq.(4) R_{eff} is the effective size of interaction region which should be of the order of a characteristic size of deutron $r_m \approx 2fm$, defined as the rms-half distance between two nucleons

$$r_m^2 = \frac{1}{4}\int_0^\infty (u^2(r) + w^2(r))r^2 dr, \tag{5}$$

with $u(r)$ and $w(r)$ are S and D waves of deutron. [4] [1]. Therefore we get the large reduction factor of

$$\frac{\sigma^{p+p\to D+e^+ +\nu}(m_\pi)}{\sigma_{FA}^{p+p\to D+e^+ +\nu}} \approx 0.65. \tag{6}$$

Thus, it is shown that nonlocality of the nucleon axial charge may lead to the large decreasing of the rate of the basic solar reaction for neutrino production and may give the mechanism to explain the solar neutrino deficiency.

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[1] More accurate estimation will be published elsewhere.

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